#8 Declaration Bentley 12/4/03

CERTIFICATE OF MAILING
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Signed: Karen A Hallock
Karen Hallock

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Appln. No.	:	09/929,738	Confirmation No. 9020
Applicant	:	EMILIO CASACCIA et al.	
Filed	:	August 13, 2001	
Title	:	SUPPRESSION OF DOUBLE RAYLEIGH BACKSCATTERING AND PUMP REUSE IN A RAMAN AMPLIFIER	
TC/A.U.	:	3663	
Examiner	:	DEANDRA M. HUGHES	
Docket No.	:	CISCP686	

Honorable Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION UNDER RULE §131

Sir:

We, Emilio Casaccia, Fabrizio Di Pasquale, and Giorgio Grasso, the inventors of the subject patent application, do hereby declare as follows:

1. That all of the work described subsequently in this declaration was performed in Italy; and that all of the work described in the declaration was either performed by one or all of us, or on our behalf.

2. Prior to April 30, 2001, the filing date of Publication No. 2002/0159132, we had conceived the subject invention, which includes an optical amplification scheme incorporating distribution of optical pump energy among two or more cascaded fiber segments.

3. Exhibit A is a photocopy of a technical report authored by the three of us prior to April 30, 2001. Dates and certain other information have been redacted. The technical report is based on ideas developed by the three of us together.

4. Exhibit A describes and illustrates features of optical amplification systems that are specific embodiments of our invention. One particular embodiment provides a two-stage Raman amplification scheme. An optical circulator is used to inject counter-propagating pump

amplification. Upon leaving this second stage fiber segment, the pump energy is directed by another circulator to a fiber Bragg grating. The grating reflects the pump energy for injection into another fiber segment used as the first amplification stage. Another embodiment described therein similarly distributes optical pump energy among three Raman amplification stages. By simulation we were able to show improved performance as a result of using embodiments of our invention. In particular, we were able to show that noise related to double Rayleigh scattering was significantly reduced. We also described and simulated a similar scheme employing multiple pump wavelengths.

5. After the conception of our invention and prior to April 30, 2001, we began working with our patent attorney on preparation of the present patent application. Work on the patent application was substantially completed by July 23, 2001 other than filing formalities. Exhibit B is a photocopy of the signature page of the patent application declaration Exhibit B shows that Emilio Casaccia signed the declaration on July 23, 2001. The application was filed on August 13, 2001.

The undersigned declarants declare further that all statements made herein of their own knowledge are true and all statements made on information and belief are believe to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Respectfully submitted,

Dated: 10/11/2003 By: Emilio Casaccia

Emilio Casaccia

Dated:__________ By:__________

Fabrizio Di Pasquale

Dated:__________ By:__________

Giorgio Grasso

RITTER, LANG & KAPLAN LLP
12930 Saratoga Ave., Suite D1
Saratoga, CA 95070
Tel: 408-446-8690 / Fax: 408-446-8691

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Respectfully submitted,

Dated:____________ By:____________
Emilio Casaccia

Dated: 4/11/2003 By: Fabrizio Di Pasquale
Fabrizio Di Pasquale

Dated:____________ By:____________
Giorgio Grasso

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Saratoga, CA 95070

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Respectfully submitted,

Dated:__________ By:__________
Emilio Casaccia

Dated:__________ By:__________
Fabrizio Di Pasquale

Dated: 11/11/2003 By: Giorgio Grasso
Giorgio Grasso

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EXHIBIT A

Patent Proposal: Suppression of Double Backscattering and pump reuse in a Raman amplifier

Authors: Emilio Casaccia, Fabrizio Di Pasquale, Giorgio Grasso

1. Index

2. Field of the invention

This invention relates to optical communication systems and, in particular, to optical communication systems with amplification provided by distributed and /or discrete Raman amplifiers.

3. Background of the invention

The explosion of communication services, ranging from video teleconferencing to electronic commerce, has spawn a new era of personal and business interactions. As evident in the enormous growth of Internet traffic, consumers have begun to embrace information technology, viewing it, in some cases, as much a necessity as the telephone. However, this new mindset poses many challenges to the telecommunication industry to develop technology that will greatly expand the bandwidth limitations of existing communication systems. Optical communications holds great promise to meet the continual demands for greater and greater bandwidth.

Wavelength Division Multiplexing, WDM, technology, in particular Dense WDM (DWDM), permits the concurrent transmission of multiple channels over a common optical fiber. The advent of Erbium Doped Fiber Amplifiers (EDFA) has accelerated the development of WDM systems by providing a cost-effective optical amplifier that is transparent to data rate and format. EDFA amplifies all the wavelengths simultaneously, enabling the composite optical signals to travel large distances (e.g., 600 km) without regeneration.

One the main limitations of the EDFAs is the limited bandwidth; discrete and distributed Raman amplifiers are very attractive to overcome this limitation. They provide very high gain across wide range of wavelengths. Moreover, discrete and distributed RAs increase the distance between optical regeneration, while allowing closer channel spacing.

The operation of RAs involves transmitting high-power laser lights in counter-propagating or co-propagating configurations with respect to the WDM signals propagation direction. These high-power laser lights amplify the WDM signals.

It is well known that one of the major cause that limits the performance of a Raman Amplifier (both discrete and distributed) is the Double Rayleigh Backscattering of the signal. We have found in Literature, that this problem can be reduced inserting optical isolators and gain flattening filters between different amplifier's stages. To our knowledge all these solutions lead to a suboptimal use of the pump power, because it's impossible to efficiently reuse the counter propagating pump from one stage to the other.

4. Summary of the invention

We have found a new scheme based on three port closed optical circulators and fiber gratings that, being wavelength dependent, breaks the onset of the signal Double Rayleigh Backscattering while letting the counter-propagating pump wavelength through. In this way the pump power can be effectively used for the entire amplifier length. This scheme applies easily also to a multi-wavelength Raman pump and to more than two-stage amplifiers and could be in principle used both in discrete and distributed counter-propagating RA.

5. Brief description of the drawings

Figure 1: Schematic structure of a single-stage counter-pumped Raman amplifier

Figure 2: $OSNR_{S\text{-}SP}$ and $OSNR_{DRS}$ versus input signal power for a single-stage Raman amplifier

Figure 3: Schematic structure of a dual-stage counter-pumped Raman amplifier

Figure 4: Schematic structure of a dual-stage counter-pumped Raman amplifier with pump reuse

Figure 5: Schematic structure of a three-stage counter-pumped Raman amplifier with pump reuse

Figure 6: $OSNR_{DRS}$ versus Raman gain for single-stage, dual-stage and three-stage Raman amplifiers

Figure 7: $OSNR_{S\text{-}SP}$ and $OSNR_{DRS}$ versus input signal power for a single-stage Raman amplifier with pump reuse

Figure 8: Schematic structure of a dual-stage counter-pumped Raman amplifier with pump reuse (dual-wavelength pump: 1470 nm and 1495 nm)

Figure 9: Net gain and $OSNR_{DRS}$ for single and dual-stage Raman amplifiers with pump reuse (32 WDM channels, 100 GHz spacing)

6. Detailed Description

1.1 Description of Raman Amplifier

Figure 1 illustrates an example of a *Raman Amplifier*, RA (with counter propagating pumpimg). It consists of a spool of fiber, an optical isolator and an open circulator (a WDM coupler can be used as an alternative). The signal enters the amplifier through the optical isolator and is amplified while travelling along the fiber spool by the laser pump via Stimulated Raman Amplification. The pump, which is inserted through the circulator, should be at a wavelength about 100 nm below the signal wavelength to maximize the efficiency. Better efficiency is obtained with a fiber with small effective area (for example Dispersion Shifted Fiber). Although RAs can be designed both with co and counter-propagating pumping schemes, the last technique is the more widely used. Our invention is relevant only for counter-propagating RAs. Our invention applies in a straightforward extension also to distributed RA with counter-propagating pumping schemes, even though, in all the following examples, we will refer only to discrete RAs.

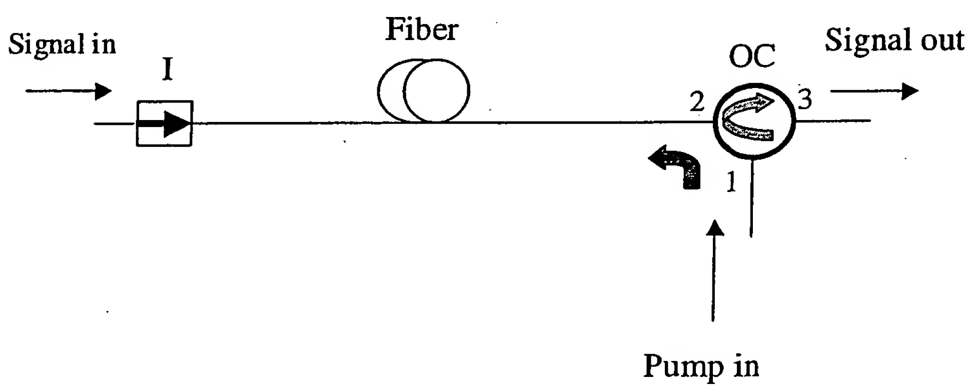

Figure 1: Example of a single-stage RA with counter-propagating pumping. I: Optical Isolator; OC: Open Optical Circulator.

1.2 Double Rayleigh Scattering limit of RA

It is well known that *Double Rayleigh Scattering*, DRS, of the signal limits the performance of RA: the signal is partly reflected by each section of the fiber inside the amplifier and then back-reflected a second time; this double reflected signals are amplified with the same local gain experienced by the signal and result in an interferometric noise at the output of the amplifier. Figure 2 shows the result of a simulation made on a single stage amplifier such as

the one shown in Figure 1. The simulation was made with a section of 16 km of DSF with an effective area of 50 um^2 and a DRS coefficient of 10^{-7} m^{-1}. The figure plots the *Optical Signal to Noise Ratio*, OSNR, (on 10 GHz resolution bandwidth) versus the input signal power due to two different noise sources: in blue the OSNR due to the *Amplified Spontaneous Emission*, ASE, noise is plotted, in red we plot the OSNR due to DRS. While the ASE induced OSNR improves increasing the input signal power, the OSNR due to DRS is constant because it depends only on the amplifier gain. As the figure shows, the overall OSNR is limited by DRS already for very low input powers (~ -32 dBm).

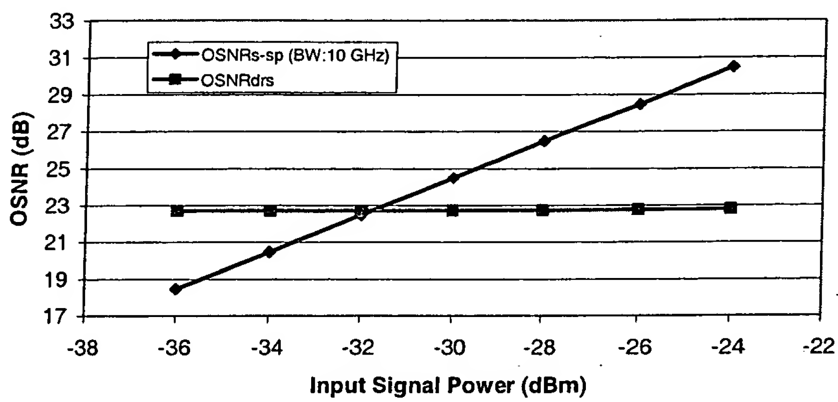

Figure 2: OSNR (dB) (on 10 GHz resolution bandwidth) versus input signal power (dBm) for a single-stage RA. Black curve refers to ASE induced OSNR, red curve to DRS induced OSNR. Calculation were done for a RA like the one depicted in Figure 1 consisting of a section of 16 km of DSF fiber with an effective area of 50 um^2 and a DRS coefficient of 10^{-7} m^{-1}. The attenuation coefficients for the signal and the pump are 0.225 dB/km and 0.26 dB/km respectively.

1.3 Previous art solution to DRS limit of RA

Since the build up of DRS is the result of the integral of double reflections by each section of the fiber where the amplification takes place, it is well known (previous art) that an effective way to reduce the build up of DRS consists in designing multi-stages Raman Amplifiers separated by optical isolators. A typical example is shown in Figure 3, where a two-stage RA is illustrated. It consists of an optical isolator at the input of the amplifier, two spools of fibers, two open optical circulators and two counter propagating pumps. While the signal is amplified by both stages, the build up of DRS is broken by the mid-stage circulator that acts effectively as an isolator for the DRS.

This scheme needs one pump for each stage and does not allow pump re-use: in the example of Figure 3, the residual pump #2 cannot be used also in stage #1 because it's blocked by the circulator #1.

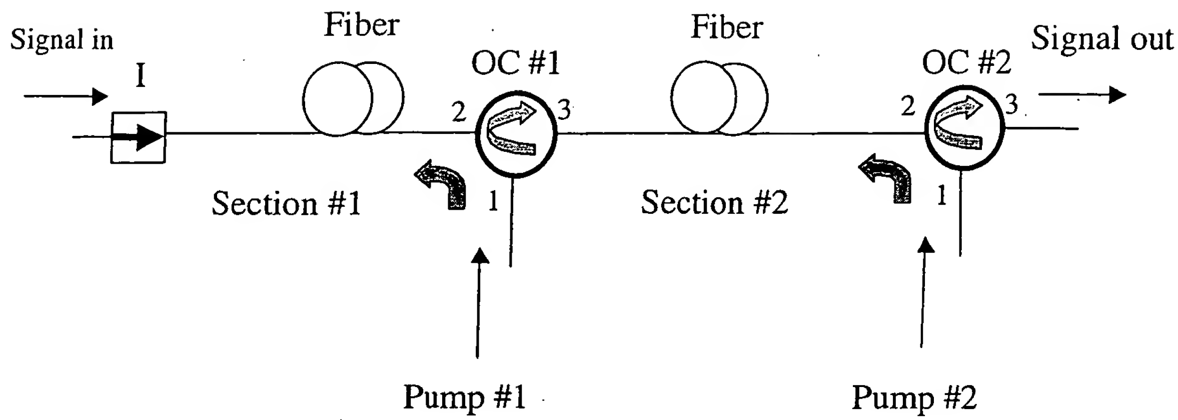

Figure 3: Two-stage RA with two counter-propagating pumps and two open optical circulators. This scheme is a typical previous art solution to reduce the DRS effect.

1.4 Our solution

The innovative scheme we propose to reduce the effect of DRS is illustrated, as an example, in Figure 4. In our scheme the mid-stage open optical circulator is substituted by a closed optical circulator and a *Fiber Bragg Grating*, FBG. In closed three-port optical circulators first and last ports (ports 3 and 1 in Figure 4) are optically connected with low loss, whereas in open three-port optical circulators the same ports are optically isolated. The FBG must be designed to have maximum reflection at the pump wavelength and to absorb all the power at the signal wavelength. In this way the remainder of the counter-propagating pump from stage #2 is transmitted from port #3 to port #1 of the mid-stage closed optical circulator, reflected by the FBG and transmitted by the circulator ports #1 and #2 to the section #1. The mid-stage open circulator together with the FBG still acts as a isolator for the signal wavelength thus breaking the build up of DRS in the same way as in the scheme of Figure 3.
The same basic idea can be extended to multi-stages amplifiers. Figure 5 shows an example of a three-stage RA according to our invention. It consists of an optical isolator three spools of fiber, two closed circulators, two FBGs and an open three-port optical circulator at the output. The pump wavelength is transmitted from one section to the next via the closed circulators and FBG, whereas the build up of DRS is broken at the end of every section.

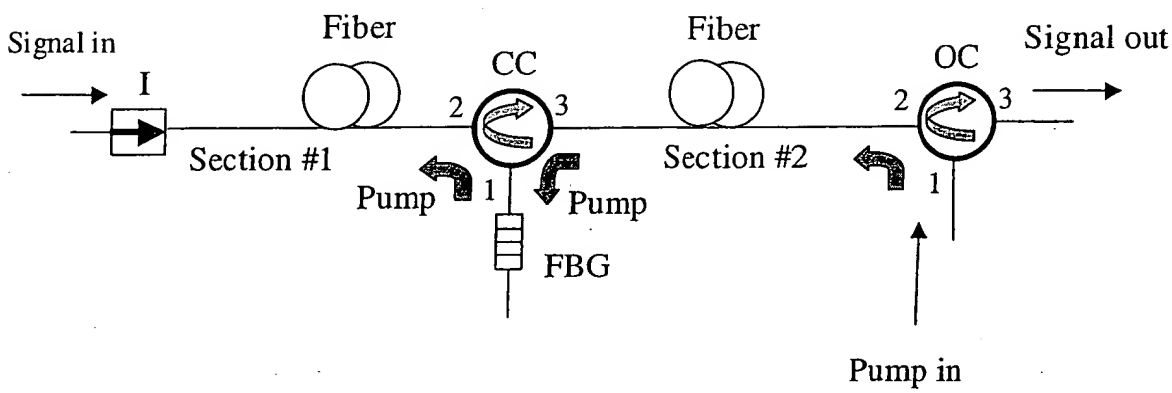

Figure 4: Two-stage RA scheme according to our invention. I: optical Isolator; CC: Closed optical Circulator; OC: Open optical Circulator; FBG: Fiber Bragg Grating.

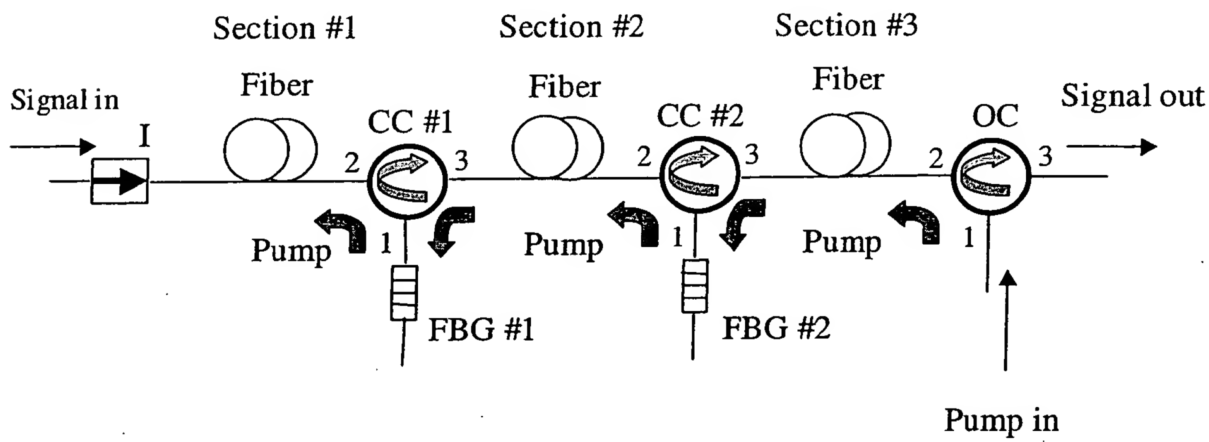

Figure 5: Three-stage RA scheme according to our invention.

1.5 Performance of our solution

Figure 6 shows the result of a simulation that confirms the improvement obtainable with our invention. The figure plots the DRS-related OSNR versus the net gain of the RA for a single, double and three-stage RA. For the simulation DCF is used with an effective area of 50 um^2 and a DRS coefficient of 10^{-7} m^{-1}. The attenuation coefficients for the signal and the pump are 0.225 dB/km and 0.26 dB/km respectively.

The improvement depends on the net gain. For a 20 dB gain there is an improvement of more than 10 dB with a two-stage amplifier and of more than 15 dB with a three-stage amplifier. A similar improvement could be obtained also with the previous art solution, but an additional pump for each stage would be needed. Figure 7 shows the limits imposed by DRS on a two-stage RA designed according to our invention. As in Figure 2, the ASE and DRS induced OSNRs are plotted versus the input signal power. The DRS limits the overall OSNR of a two-stage RA at about -12 dBm input power, an improvement of 20 dB with respect to a single-stage RA. Since in fiber optic transmission system input powers are in the range below –20 dBm, the performance of our two-stage RA is not limited by DRS anymore.

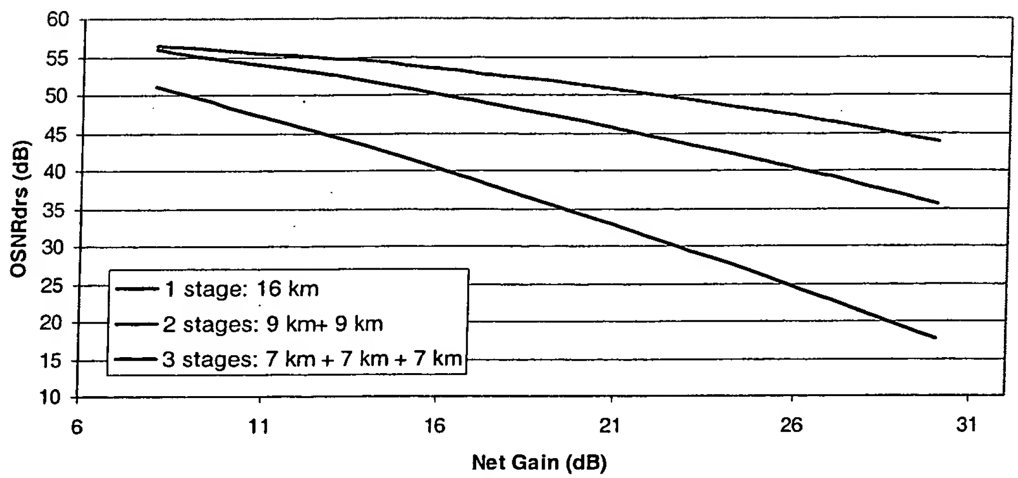

Figure 6: DRS induced OSNR (dB) versus amplifier net gain (dB) for single-stage, tw-stage and three-stage RA. Black curve: single-stage RA with a section of 16 km of DSF; Blue curve: two-stage RA (scheme as in Figure 4) with two sections of 9 km of DSF; Red curve: three-stage RA (scheme as in Figure 5) with three sections of 7 km of DSF. Effective area of all fiber sections is 50 um^2; DRS coefficient is always 10^{-7} m^{-1}. The attenuation coefficients for the signal and the pump are 0.225 dB/km and 0.26 dB/km respectively.

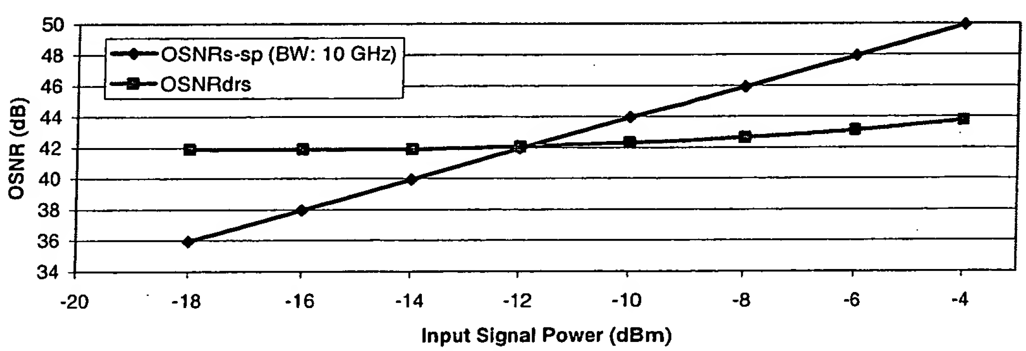

Figure 7: OSNR (dB) (on 10 GHz resolution bandwidth) versus input signal power (dBm) for a two-stage RA. Black curve refers to ASE induced OSNR, red curve to DRS induced OSNR. Calculation were done for a RA like the one depicted in Figure 4 consisting of two sections of 9 km of DSF fiber with an effective area of 50 um^2 and a DRS coefficient of 10^{-7} m^{-1}. The attenuation coefficients for the signal and the pump are 0.225 dB/km and 0.26 dB/km respectively.

1.6 Our solution with multi-wavelength pumping.

In order to widen or to achieve a better flatness over the amplifier's bandwidth, more than one pump wavelength can be used in RAs. Our invention can be extended to a multi-wavelength pump RAs by cascading several FBGs, each designed to reflect a specific pump wavelength. Figure 8 illustrates an example of a two-stage RA with two pump wavelengths. It consists of an optical isolator at the input, two fiber sections, a closed optical circulator, two FBGs, an open optical circulator and a *Wavelength Division Multiplexer*, WDM, pump coupler. The two pumps at the two different wavelengths are coupled by the WDM and then inserted inside the fiber by the open circulator. After counter-propagation through section #2, the two pump wavelengths are transmitted by ports #3 and #1 to the FBGs. FBG #1 reflects pump wavelength #1 and transmits pump wavelength #2, while FBG #2 is designed to reflect pump wavelength #2. All other wavelengths are absorbed by both FBGs. The reflected pumps are inserted into section #1 via ports #1 and #2 of the mid-stage closed circulator. The mid-stage closed circulator together with the two FBGs still acts as an optical isolator for the signal wavelength. In this way both pumps can be re-used through section #1 and still the build up of DRS is broken by the insertion of the mid-stage circulator.

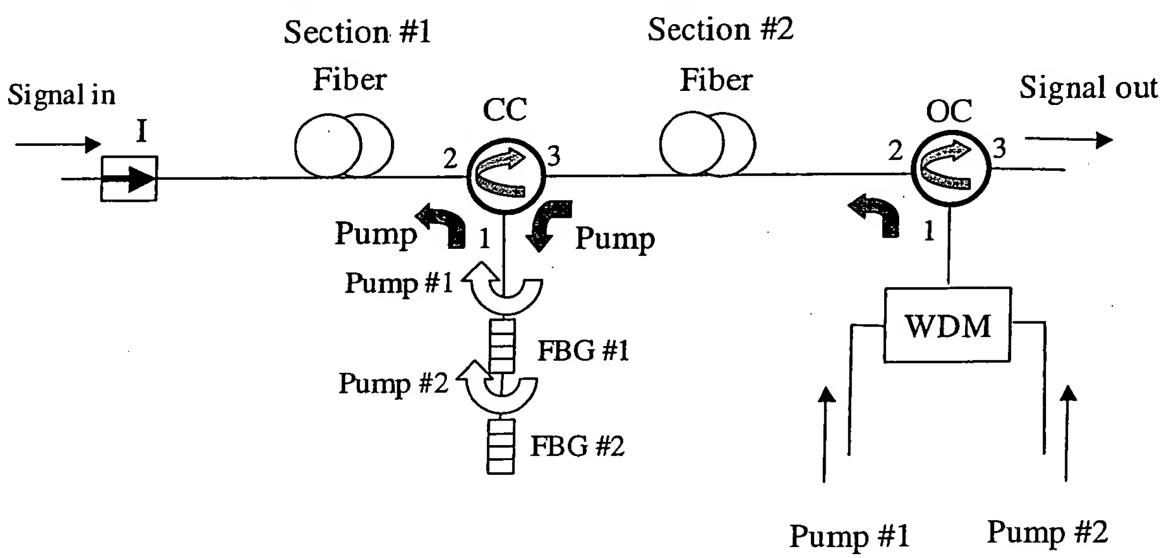

Figure 8: Two-stage RA with two-wavelength pumping according to our invention. WDM: Wavelength Division Multiplexer.

1.7 Performance of our multi-wavelength pump solution.

Figure 9 shows the results of a simulation that demonstrates the improvement that can be obtained with a two-stage multi-wavelength pumped RA designed according to our invention with respect to a conventional single-stage RA. The figure plots the net gain versus wavelength for both amplifiers (Red curve for a 16 km single-stage RA, Black curve for a two-stage 9+9 km RA). The two amplifiers have almost identical gain and flatness. The figure also plots the DRS induced OSNR for the two kind of RA (Blue curve for the single-stage RA, Green Curve for the two-stage RA). The two-stage RA designed according to our

invention clearly shows an improvement in DRS induced OSNR of more than 10 dB over the entire amplifier bandwidth.

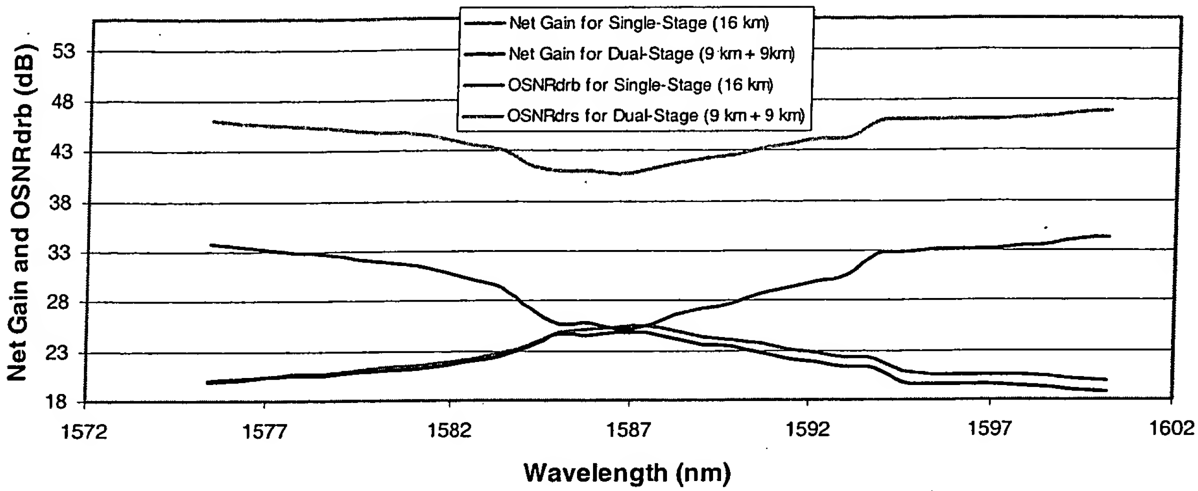

Figure 9: Comparison of performances between single and two-stage Ras with two wavelength-pumping. Red curve: net gain (dB) versus wavelength (nm) for a single stage RA made of 16 km of DSF. Black curve: net gain versus wavelength for a two-stage RA made of two sections of DSF 7 km long (see Figure 8). Blue curve: DRS induced OSNR versus wavelength for the same single-stage RA. Green curve: DRS induced OSNR versus wavelength for the same two-stage RA. The effective area of all sections is 50 um^2, the DRS coefficient is always 10^{-7} m^{-1}. The attenuation coefficients for the signal and the pump are 0.225 dB/km and 0.26 dB/km respectively.

7. Advantages

It is a more straight forward solution than others we have found in literature, and it allows the efficient reuse of the multiwavelength pump power along all the amplifiers' stages.

8. Prior art literature:

1) "Broadband high gain dispersion compensating Raman amplifier", S.A.E Lewis, S.W. Chernikov and J.R. Taylor, Electronics Letters,Vol. 36, No. 16, pp 1355-1356.

2) "Characterization of Double Rayleigh Scatter Noise in Raman Amplifiers", S.A.E Lewis, S.W. Chernikov and J.R. Taylor, IEEE Photonics Technology Letters, Vol. 12, No. 5, May 2000.

3) "Rayleigh Crosstalk in long cascades of distributed unsaturated Raman amplifiers", M. Nissov, K. Rottwitt, H.D. Kidorf and M.X. Ma, Electronics Letters, Vol. 35, No. 12, pp 997-998.